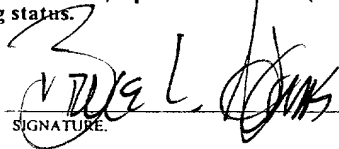


FORM PCT-1390 (REV 11-98)		U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER S004-4144 (PCT)	
<b>TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371</b>				U.S. APPLICATION NO. (If known, see 37 CFR 1.5) <div style="font-size: 1.5em; font-weight: bold;">09/700640</div>	
INTERNATIONAL APPLICATION NO. PCT/JP00/02062		INTERNATIONAL FILING DATE 31 March 2000 (31.03.00)		PRIORITY DATE CLAIMED 31 March 1999 (31.03.99)	
TITLE OF INVENTION <div style="text-align: center;">MAGNETIC BEARING APPARATUS AND VACUUM PUMP</div>					
APPLICANT(S) FOR DO/EO/US <div style="text-align: center;">Akira YAMAUCHI et al.</div>					
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information.					
<ol style="list-style-type: none"> <li>1. <input checked="" type="checkbox"/> This is a <b>FIRST</b> submission of items concerning a filing under 35 U.S.C. 371.</li> <li>2. <input type="checkbox"/> This is a <b>SECOND</b> or <b>SUBSEQUENT</b> submission of items concerning a filing under 35 U.S.C. 371.</li> <li>3. <input checked="" type="checkbox"/> This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).</li> <li>4. <input checked="" type="checkbox"/> A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date</li> <li>5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371(c)(2))               <ol style="list-style-type: none"> <li>a. <input type="checkbox"/> is transmitted herewith (required only if not transmitted by the International Bureau).</li> <li>b. <input checked="" type="checkbox"/> has been transmitted by the International Bureau.</li> <li>c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US).</li> </ol> </li> <li>6. <input checked="" type="checkbox"/> A translation of the International Application into English (35 U.S.C. 371(c)(2)).</li> <li>7. <input type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))               <ol style="list-style-type: none"> <li>a. <input type="checkbox"/> are transmitted herewith (required only if not transmitted by the International Bureau).</li> <li>b. <input type="checkbox"/> have been transmitted by the International Bureau.</li> <li>c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired.</li> <li>d. <input type="checkbox"/> have not been made and will not be made.</li> </ol> </li> <li>8. <input type="checkbox"/> A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).</li> <li>9. <input type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).</li> <li>10. <input type="checkbox"/> A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).</li> </ol>					
<b>Items 11. to 16. below concern document(s) or information included:</b>					
<ol style="list-style-type: none"> <li>11. <input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98.</li> <li>12. <input type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.</li> <li>13. <input type="checkbox"/> A FIRST preliminary amendment.  <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment.</li> <li>14. <input type="checkbox"/> A substitute specification.</li> <li>15. <input type="checkbox"/> A change of power of attorney and/or address letter.</li> <li>16. <input checked="" type="checkbox"/> Other items or information:  <div style="margin-left: 20px;">           Form PCT/1B/301            Form PCT/1B/308            Patent Cover Page            Form PCT/ISA/210         </div> </li> </ol>					

US

Annex US.II, page 2

PCT Applicant's Guide - Volume II - National Chapter - US

<b>09/700640</b> US APPLICATION NO. (if known)		INTERNATIONAL APPLICATION NO. <b>PCT/JP00/02062</b>		ATTORNEY'S DOCKET NUMBER <b>S004-4144 (PCT)</b>	
17. <input checked="" type="checkbox"/> The following fees are submitted: <b>BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):</b> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO. .... \$970.00  International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO ..... \$840.00  International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... \$760.00  International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) ..... \$670.00  International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) ..... \$96.00  <b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>				<b>CALCULATIONS</b> PTO USE ONLY	
<b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>				<b>\$ 860.00</b>	
Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				<b>\$</b>	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	8 - 20 =	0	X \$18.00	\$	
Independent claims	1 - 3 =	0	X \$78.00	\$	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ \$260.00	\$ 270.00	
<b>TOTAL OF ABOVE CALCULATIONS =</b>				<b>\$ 1130.00</b>	
Reduction of 1/2 for filing by small entity, if applicable. A Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28).				<b>\$</b>	
<b>SUBTOTAL =</b>				<b>\$ 1130.00</b>	
Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				<b>\$</b>	
<b>TOTAL NATIONAL FEE =</b>				<b>\$ 1130.00</b>	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property				<b>\$</b>	
<b>TOTAL FEES ENCLOSED =</b>				<b>\$ 1130.00</b>	
				Amount to be:	\$
				refunded	\$
				charged	\$
a. <input checked="" type="checkbox"/> A check in the amount of <u>\$1130.00</u> to cover the above fees is enclosed.					
b. <input type="checkbox"/> Please charge my Deposit Account No. _____ in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.					
c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <u>01-0268</u> . A duplicate copy of this sheet is enclosed.					
<b>NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.</b>					
SEND ALL CORRESPONDENCE TO Bruce L. Adams, Esq. Adams & Wilks 50 Broadway-31st Fl. New York, NY 10004					
				 SIGNATURE	
				Bruce L. Adams NAME	
				<u>25,386</u> REGISTRATION NUMBER	

## DESCRIPTION

## MAGNETIC BEARING APPARATUS AND VACUUM PUMP

## TECHNICAL FIELD

The present invention relates to a magnetic bearing apparatus provided with a touchdown bearing made of a pair of roller bearings and a pair of corrugated plate-like damper members inserted into an annular gap formed between the touchdown bearing and its retainer member and a vacuum pump provided with this, and more particularly to an improvement in durability of a touchdown bearing and corrugated damper members for absorbing shock upon the touchdown and suppressing to a sufficiently low level a vibratory rotational frequency of a rotor relative to a rotational frequency of the rotor.

## BACKGROUND ART

A magnetic bearing apparatus provided at least with a rotor shaft, a radial magnetic bearing for supporting the rotor shaft in a radial direction, a thrust magnetic bearing for supporting the rotor shaft in an axial direction and a touchdown bearing is adopted in, for example, a vacuum pump such as a turbo molecular pump and has been extensively practiced. The above touchdown bearing is a protective bearing for receiving the above rotor shaft in case of emergency like a breakdown of the magnetic bearing and is composed

of, for example, a pair of roller bearings arranged at a lower end portion of the above rotor shaft. Such a magnetic bearing apparatus and the turbo molecular pump provided with this are disclosed in JP-A-10-89284, JP-A-63-239397 and the like.

Also, the corrugated plate-like damper member adopted in such a magnetic bearing apparatus is a member for suppressing a vibratory rotation, i.e., a swivel motion and simultaneously absorbing the shock of the touchdown when the rotor including the rotor shaft touches down to the touchdown bearing. This corrugated plate-like damper member functions as three members of a spring, a damper and a mechanical stop as one member as disclosed in JP-B-7-103894, and is, for example, a corrugated strip steel plate as shown in Fig. 6.

In Fig. 5, the corrugated plate-like damper member is composed of a pair of corrugated strip steel plates 8a and 8b inserted into an annular gap G formed between outer races of a pair of roller bearings 4a and 4b constituting the touchdown bearing 4 and an inner circumferential surface of a retainer member 9 of the touchdown bearing. The frequency  $f=(k/m)^{1/2}$  determined by the rigidity k of the corrugated strip steel plates 8a and 8b and the rotor mass m is identified with the vibratory rotational frequency of the rotor upon the touch down. The collision energy E upon the touchdown of the rotor is in proportion to the second powered value of the frequency f, i.e.,  $(k/m)$ . From these relationships, it will be

understood that the smaller the rigidity  $k$ , the larger the effect of the corrugated strip steel plates 8a and 8b will become as the damper member. In order to reduce the rigidity  $k$ , it is available to reduce the thickness  $t$  of the corrugated strip steel plates 8a and 8b, for example, but the function of the corrugated strip steel plates 8a and 8b as the stop is degraded as the thickness  $t$  is decreased.

In order to cause the corrugated strip steel plate 8 to serve as a stop with a rigidity to some extent against the shock upon the touchdown of the rotor, the pitch  $p$  of the waveform, the height  $h$  under the non-load condition and the thickness  $t$  of the corrugated strip steel plate 8 could not be reduced as desired, as a result of which the width  $B$  has to be reduced. For this reason, the height  $H$  of the roller bearing would be twice greater than the width  $B$  of the corrugated strip steel plate 8 or more. In other words, in some cases, the corrugated strip steel plate 8 having a width that is less than half the height  $H$  of the roller bearing must be used. The corrugated strip steel plates 8a and 8b that have small pitch  $p$ , height  $h$  and thickness  $t$  and a width that is less than half the height  $H$  of the roller bearing are provided with a small retaining force. Accordingly, in the case where such corrugated strip steel plates 8a and 8b having the smaller width are inserted into the annular gap  $G$ , due to the vibration caused by the use for a long period of time, the upper corrugated strip steel plate 8a is offset

downwardly so that it is brought into contact with the lower corrugated strip steel plate 8b. As a result, in some cases, the first rotary bearing 4a is kept free by width  $\delta$  in the radial direction to be brought into contact with the rotor to generate abnormal noise or abnormal frictional wear. Incidentally, the width  $\delta$  is the width of the annular gap G. In such a condition, the corrugated plate-like damper member could not exhibit the inherent function and could generate abnormal vibration or swing in the vacuum pump provided with the magnetic bearing apparatus or the magnetic bearing to bring about a breakdown in the apparatus as a whole.

In a magnetic bearing apparatus provided at least with a rotor shaft, a radial magnetic bearing for supporting the rotor shaft in a radial direction, a thrust magnetic bearing for supporting the rotor shaft in an axial direction, a touchdown bearing composed of a pair of roller bearings arranged at a lower end portion of the above rotor shaft, a pair of corrugated plate-like damper members inserted into an annular gap between the touchdown bearing and its retainer member and a vacuum pump provided with this, an object of the present invention is to keep on retaining the pair of corrugated plate-like damper member in a predetermined position without fail.

DISCLOSRE OF THE INVENTION

In order to solve the above-noted problems, there is provided a magnetic bearing apparatus provided at least with a rotor shaft, a radial magnetic bearing for supporting the rotor shaft in a radial direction, a thrust magnetic bearing for supporting the rotor shaft in an axial direction, a touchdown bearing composed of a pair of roller bearings arranged to surround a lower end portion of the rotor shaft, a pair of corrugated plate-like damper members inserted into an annular gap between the touchdown bearing and its retainer member and a vacuum pump provided with this, being provided with a positional offset preventing means of the corrugated plate-like damper member in the annular gap.

Then, a metal thin plate interposed between the pair of corrugated plate-like damper members is used as the positional offset preventing means of the corrugated plate-like damper member.

Also, an annular convex portion formed in an inner circumferential surface of the retainer member is used as the positional offset preventing means of the corrugated plate-like damper member.

Further, an annular concave portion formed in an inner circumferential surface of the retainer member is used as the positional offset preventing means of the corrugated plate-like damper member.

Furthermore, when the positional offset preventing means of the corrugated plate-like damper member is constructed, a thickness

of a metal thin plate, a sum ( $T+t$ ) of a height of the annular convex portion or a depth of the annular concave portion  $T$  and a thickness  $t$  of a corrugated strip steel plate is 0.8 to 1.3 times of a width  $\delta$  of the annular gap.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a partially perspective view of a touchdown bearing and a corrugated plate-like damper member in accordance with a first embodiment of a magnetic bearing apparatus of the present invention.

Fig. 2 is a cross-sectional view of a touchdown bearing and a corrugated plate-like damper member in accordance with a second embodiment of a magnetic bearing apparatus of the present invention.

Fig. 3 is a cross-sectional view of a touchdown bearing and a corrugated plate-like damper member in accordance with a third embodiment of a magnetic bearing apparatus of the present invention.

Fig. 4 is a developed view showing various embodiments of an upper stage corrugated strip steel plate 8a, a lower stage corrugated strip steel plate 8b and a strip-like metal thin plate 10a clamped therebetween in accordance with the first embodiment of the magnetic bearing apparatus of the present invention.

Fig. 5 is a partially perspective view of a touchdown bearing and a corrugated plate-like damper member of a conventional magnetic bearing apparatus.

Fig. 6 is a partially perspective view of a corrugated strip

steel plate that is a corrugated plate-like damper member.

Fig. 7 is a longitudinal sectional view of one embodiment of a vacuum pump according to the present invention.

#### BEST MODE FOR CARRYING OUT THE INVENTION

Preferable embodiments of the present invention will now be described with reference to Figs. 1 to 7 in more detail.

Fig. 7 is a longitudinal sectional view of one embodiment of a turbo molecular pump to which the present invention is applied. This turbo molecular pump has basically the same structure as that disclosed in JP-A-10-89284 and is composed of a rotor 6 including a rotor shaft 1, a stator 7 and a magnetic bearing apparatus for supporting the rotor 6 rotatably as desired. The rotor 6 includes a rotor cylindrical member in which a number of rotor blades are mounted on the upper side and a cylindrical portion having a flat outer circumferential surface is formed on the lower side beside the rotor shaft 1. The stator 7 includes a stator cylindrical member in which a number of stator blades are mounted on the upper side and a cylindrical portion having a screwed inner circumferential surface is formed on the lower side.

The above-described magnetic bearing apparatus is a so-called five axis controlling type magnetic bearing apparatus and is constituted of a radial magnetic bearing 2 composed of a first radial magnetic bearing 2a disposed on the upper side of the rotor shaft

1 and a second radial magnetic bearing 2b disposed on the lower side, a thrust magnetic bearing 3 composed of a first thrust magnetic bearing 3a and a second thrust magnetic bearing 3b disposed at a lower end portion of the rotor shaft 1, and a high frequency motor 5 disposed in an intermediate portion of the rotor shaft 1.

The above-described magnetic bearing apparatus further includes a touchdown bearing 4 disposed between the first thrust magnetic bearing 3a in an upper stage and the lower end portion of the rotor shaft and a corrugated plate-like damper member for absorbing the shock upon the touchdown and for attenuating the swivel frequency of the rotor. The touchdown bearing 4 is composed of a pair of roller bearings disposed in upper and lower stages, i.e., a first roller bearing 4a and a second roller bearing 4b. Although not shown in Fig. 7, the corrugated plate-like damper member is inserted into the annular gap formed between the touchdown bearing 4 and the retainer member thereof.

In Fig. 1 showing a first embodiment of the present invention, a cylindrical retainer member 9 serves as both the thrust bearing retainer member and the touchdown bearing retainer member. Namely, the retainer member 9 is the retainer member coated with resin mold and formed into a cylinder for receiving electromagnets constituting the thrust bearing 3a of Fig. 7. Then, the touchdown bearing 4, i.e., the pair of roller bearings 4a and 4b disposed in the upper and lower stages are received in the inner

circumferential portion of the retainer member 9. The annular gap G is formed between the inner circumferential surface of the cylindrical retainer member 9 and the outer races of the pair of roller bearings 4a and 4b, a pair of corrugated strip steel plates 8a and 8b that form the corrugated plate-like damper member are inserted into this annular gap G, and a strip-like metal thin plate 10a is inserted while being clamped by the upper corrugated strip steel plate 8a and the lower corrugated strip steel plate 8b. The corrugated strip steel plates 8a and 8b are, for instance, the corrugated strip steel plates as shown in Fig. 6.

The pair of roller bearings 4a and 4b are depressed in the radial direction by the elasticity of the corrugated strip steel plates 8a and 8b and retained over the inner circumferential portion of the retainer member 9. The corrugated strip steel plates 8a and 8b are also retained in a predetermined position within the annular gap G by the elasticity thereof. In addition, since the corrugated strip steel plates 8a and 8b are inserted into the annular gap G through the strip-like metal thin plate 10a in the axial direction, there is no positional offset or drop and the plates are always retained in the predetermined position without fail. Briefly, the strip-like metal thin plate 10a is a means for preventing the positional offset of the corrugated plate-like damper member.

By the way, the selection of the metal thin plate 10a and the determination of the width  $\delta$  of the annular gap relate to the

thickness  $T$  of the metal thin plate 10a, the thickness  $t$  of the corrugated strip steel plates and the width  $\delta$  of the annular gap mutually. In the case where the value obtained by subtracting the thickness  $t$  of the corrugated strip steel plates from the width  $\delta$  of the annular gap is small, the movable amount of the corrugated portion of the corrugated strip steel plates, i.e., the radial movable amount of the rotor is reduced, resulting in disability to obtain the necessary elastic force. Inversely, in the case where the value obtained by subtracting the thickness  $t$  of the corrugated strip steel plates from the width  $\delta$  of the annular gap is large, the effect to prevent the positional offset of the metal thin plate is diminished. Therefore, according to the first embodiment, the selection of the metal thin plate 10a and the determination of the width  $\delta$  of the annular gap are performed so that the sum  $(T+t)$  of the thickness  $T$  of the metal thin plate 10a and the thickness  $t$  of the corrugated strip steel plates is 0.8 to 1.3 times of the width  $\delta$  of the annular gap. Thus, the effect to prevent the positional offset of the corrugated plate-like damper member is further enhanced.

In Fig. 2 showing a second embodiment of the present invention, the positional offset preventing means of the corrugated plate-like damper member is an annular convex portion 10b formed on the inner circumferential surface of a cylindrical retainer member 9. An annular gap  $G$  is divided into the upper and lower stages by this

annular convex portion 10b. Then, a corrugated strip steel plate 8b and a corrugated strip steel plate 8a are inserted into the lower annular gap and the upper annular gap, respectively. Accordingly, also in the second embodiment, the corrugated strip steel plates 8a and 8b are always held in a predetermined position of the annular gap G without fail. Incidentally, the height T of the annular convex portion and the width  $\delta$  of the annular gap are determined so that the sum (T+t) of the height T of the annular convex portion and the thickness t of the corrugated strip steel plates is 0.8 and 1.3 times of the width  $\delta$  of the annular gap. Thus, the effect to prevent the positional offset of the corrugated plate-like damper member is further enhanced.

In Fig. 3 showing a third embodiment of the present invention, the positional offset preventing means of the corrugated plate-like damper member is an annular concave portion 10c formed in the inner circumferential surface of the cylindrical retainer member 9. A single corrugated strip steel plate 8c is inserted into this annular concave portion 10c. Accordingly, also in the third embodiment, the corrugated strip steel plate 8c is always held in a predetermined position of an annular gap G without fail. Incidentally, the depth T of the annular concave portion and the width  $\delta$  of the annular gap are determined so that the sum (T+t) of the depth T of the annular concave portion and the thickness t of the corrugated strip steel plate is 0.8 and 1.3 times of the width  $\delta$  of the annular gap. Thus,

the effect to prevent the positional offset of the corrugated plate-like damper member is further enhanced. In the first embodiment and the second embodiment, two corrugated plate-like damper members are used. However, in the third embodiment, the single wide corrugated plate-like damper member is used, thereby the cost is advantageously reduced.

In the present invention, the sum  $(T+t)$  of the height of the metal thin plate, the height of the annular convex portion or the depth of the annular concave portion  $T$  and the thickness  $t$  of the corrugated strip steel plate is 0.8 to 1.3 times of the width  $\delta$  of the annular gap. The reason for this is as follows.

For example, assume that in the embodiment in which the thickness  $t$  of the corrugated strip steel plates is 0.1 mm, the height  $h$  of the corrugated strip steel plates is 0.25 mm and the width  $\delta$  of the annular gap is 0.2 mm, the corrugated strip steel plates are buckled or aged due to the use for a long period of time, or the height becomes  $h'$ . The height  $h$  of the corrugated strip steel plates becomes half the length of 0.25 mm and  $h'$  becomes 0.125 mm. In order that the corrugated strip steel plate buckled or aged due to the use for a long period time serves as the corrugated plate-like damper member, the relation,  $\delta < (h' + T)$  should be established. This is the reason why the corrugated strip steel plates are offset from the predetermined position unless this relationship is met. If the above-described values are substituted into this formula, the

relationship,  $T > 0.075$  mm, is established. If the thickness  $t = 0.1$  mm is added to the right side and the left side of this formula, the relationship,  $(T+t) > 0.175$  mm is given. This value, 0.175 mm, is about 0.8 times of the width  $\delta = 0.2$  mm of the annular gap.

Also, the movable amount  $\chi$  (amount of change of the corrugated plate-like damper member) of the rotor that is necessary upon the touchdown of the rotor is represented by  $\chi = (\delta - t)/2$ . When the above-described value is substituted for this, the relationship,  $\chi = 0.05$  mm is obtained. In order not to limit the motion of the rotor by the depth  $T$  of the annular concave portion or the height of the annular convex portion and the thickness of the metal thin plate, it is necessary to meet the relationship,  $(\delta - \chi) > T$ . If the above-described values are substituted into this formula, it is possible to obtain  $T < 0.15$  mm. If the thickness  $t = 0.1$  mm is added to the right side and the left side of this formula, the relationship,  $(T+t) < 0.25$  mm is given. This value, 0.25 mm, is about 1.3 times of the width  $\delta = 0.2$  mm of the annular gap.

By the way, in the first embodiment shown in Fig. 1, the pair of corrugated strip steel plates 8a and 8b that constitute the corrugated plate-like damper member and the metal thin plate 10a clamped by these plates have portions in contact with each other at the end faces in the axial direction. Therefore, the corrugated strip steel plates 8a and 8b are prevented from serving as springs. Namely, when the mass of the rotor is  $m$  and the spring rigidity

of the corrugated plate-like damper member is  $k$ , the proper frequency  $f$  [Hz] upon the touchdown of the rotor is represented by  $f = (1/2 \pi) (k/m)^{1/2}$ . The energy  $E$  applied to the cylindrical retainer member 9 upon the touchdown has a proportional relation with the product  $mf^2$  of the second powered value  $f^2$  of the frequency  $f$  and the mass  $m$ . For instance, in the case where the proper frequency  $f$  is one third of the rated rotation frequency  $f_0$  of the rotor, the above-described energy  $E$  may be reduced one ninth theoretically by the corrugated plate-like damper member. However, since the pair of corrugated strip steel plates 8a and 8b and the metal thin plate 10a clamped by these plates have portions in contact with each other at the end faces in the axial direction, the corrugated plate-like damper member is prevented from serving as the spring. If so, there is a problem that the effect of the corrugated plate-like damper member for considerably reducing the energy  $E$  applied to the cylindrical retainer member 9 upon the touchdown would be degraded.

Various embodiments for solving this problem are shown in Fig. 4. In any of the modified embodiments of Figs. 4(B) to Fig. 4(E) which are modifications to the basic embodiment of Fig. 4(A), the contact portion in the axial direction is reduced. Namely, Fig. 4(B) shows an embodiment in which a rectangular corrugated strip steel plate 8a without any cutaway portion, a rectangular corrugated strip steel plate 8b without any cutaway portion and a rectangular

thin steel plate 10a with cutaway portions in the upper and lower side surfaces are used in combination. Fig. 4(C) shows an embodiment in which a rectangular corrugated strip steel plate 8a with cutaway portions in the lower side surface, a rectangular corrugated strip steel plate 8b with cutaway portions in the upper side surface and a rectangular thin steel plate 10a without any cutaway portion are used in combination. Furthermore, Fig. 4(D) shows an embodiment in which a rectangular corrugated strip steel plate 8a with cutaway portions in the upper side surface, a rectangular corrugated strip steel plate 8b with cutaway portions in the lower side surface and a rectangular thin steel plate 10a without any cutaway portion are used in combination. Moreover, Fig. 4(E) shows an embodiment in which a rectangular corrugated strip steel plate 8a with cutaway portions in the upper and lower side surfaces, a rectangular corrugated strip steel plate 8b with cutaway portions in the upper and lower side surfaces and a rectangular thin steel plate 10a without any cutaway portion are used in combination.

The energy reduction effect by these modified embodiments will now be described. The entire energy  $E_{t1}$  upon the touchdown in the basic embodiment of Fig. 4(A) is represented by  $E_{t1} = \alpha \{ (G_1/2\pi)f^2 + (G_2/2\pi)f_0^2 \}$  where  $\alpha$  is the proportional constant. Then in the case where the proper frequency  $f$  is one third of the rated rotational frequency  $f_0$  of the rotor, the entire energy  $E_{t1}$  is  $E_{t1} = \alpha (f_0^2/2\pi)(G_1/9 + G_2)$  where  $G_1$  is the vibration level of the rotor upon

the touchdown and  $G_2$  is the vibration level at the rated rotational frequency.

The vibration level  $G_1$  of the rotor upon the touchdown in case of the basic embodiment of Fig. 4(A) is 0.5 and the vibration level  $G_2$  at the rated rotational frequency of the rotor is 0.1. Accordingly, the entire energy  $E_{t1}$  upon the touchdown is represented by  $E_{t1} = \alpha (f_0^2/2\pi) 0.5/9 + 0.1 = 0.156 \alpha (f_0^2/2\pi)$ .

In the modified embodiments of Fig. 4(B) to Fig. 4(E), the entire energy  $E_{t2}$  upon the touchdown is represented by  $E_{t2} = \alpha \{ (G_3/2\pi) f^2 + (G_4/2\pi) f_0^2 \}$ . In the case where the proper frequency  $f$  is one third of the rated rotational frequency  $f_0$  of the rotor, the entire energy  $E_{t2}$  is represented by  $E_{t2} = \alpha (f_0^2/2\pi) (G_3/9 + G_4)$  where  $G_3$  is the vibration level of the rotor upon the touchdown in the case where the contact portion of the corrugated plate-like damper member to the metal thin plate is one third of the non-contact portion, and  $G_4$  is the vibration level at the rated rotational frequency of the rotor.

The vibration level  $G_3$  of the rotor upon the touchdown in case of the modified embodiments of Fig. 4(B) and Fig. 4(C) is 1.0 and the vibration level  $G_4$  at the rated rotational frequency of the rotor is 0.01. Accordingly, the entire energy  $E_{t2}$  upon the touchdown is represented by  $E_{t2} = \alpha (f_0^2/2\pi) (1/9 + 0.01) = 0.121 \alpha (f_0^2/2\pi)$ . This is 78% of the entire energy of  $0.156 \alpha (f_0^2/2\pi)$  upon the touchdown in the basic embodiment. Therefore, according to the modified

embodiments of Fig. 4(B) and Fig. 4(C), it is possible to further reduce the energy by 22% compared with the basic embodiment of Fig. 4(A). In the same manner, also in the modified embodiments of Fig. 4(D) and Fig. 4(E), it is possible to further reduce the energy compared with the basic embodiment of Fig. 4(A).

Incidentally, in Figs. 1 to 3, the cylindrical retainer member 9 is the retainer member that receives electromagnets forming the thrust bearing 3a, molded of resin and formed into a cylindrical shape. However, this may be formed with another structure, for example, a structure integral with a stator column of the magnetic bearing apparatus.

#### INDUSTRIAL APPLICABILITY

According to the present invention, there is provided a magnetic bearing apparatus provided at least with a touchdown bearing and a pair of corrugated plate-like damper members inserted into an annular gap with a retainer member thereof and a vacuum pump provided with this, being provided with a positional offset preventing means of the corrugated plate-like damper member in the annular gap. Accordingly, since the corrugated plate-like damper members are held in a predetermined position without fail even if they are narrow corrugated strip steel plates, it is possible that the corrugated plate-like damper members are prevented from being offset to occur abnormal contact between the rotor and the touchdown

bearing. In addition, since the positional offset preventing means of the above corrugated plate-like damper member is simple in structure, it is possible to reduce the increase of the manufacture cost thereby as much as possible. Furthermore, there is no positional offset, and there is no unduly strong external force. Thus, the durability of the corrugated plate-like damper member per se is enhanced and the necessity to exchange the parts upon the overhaul is obviated.

## CLAIMS

1. A magnetic bearing apparatus provided at least with a rotor shaft, a radial magnetic bearing for supporting said rotor shaft in a radial direction, a thrust magnetic bearing for supporting said rotor shaft in an axial direction, a touchdown bearing composed of a pair of roller bearings arranged to surround a lower end portion of said rotor shaft, and a corrugated plate-like damper member inserted into an annular gap between said touchdown bearing and its retainer member, characterized by comprising a positional offset preventing means of said corrugated plate-like damper member provided in said annular gap.

2. The magnetic bearing apparatus according to claim 1, characterized in that said corrugated plate-like damper member is composed of a pair of corrugated plate-like damper members and said positional offset preventing means is a metal thin plate interposed between said pair of corrugated plate-like damper members.

3. The magnetic bearing apparatus according to claim 1, characterized in that said corrugated plate-like damper member is composed of a pair of corrugated plate-like damper members and said positional offset preventing means is an annular convex portion formed in an inner circumferential surface of said retainer member for separating said pair of corrugated plate-like damper members up and down.

4. The magnetic bearing apparatus according to claim 1,

characterized in that said positional offset preventing means is an annular concave portion formed in an inner circumferential surface of said retainer member for receiving said corrugated plate-like damper member.

5. The magnetic bearing apparatus according to claim 2, 3 or 4, characterized in that a thickness of a metal thin plate, a sum  $(T+t)$  of a height of annular convex portion or a depth of an annular concave portion  $T$  and a thickness  $t$  of a corrugated strip steel plate is 0.8 to 1.3 times of a width  $\delta$  of the annular gap.

6. A vacuum pump provided with the magnetic bearing apparatus according to claim 1.

# ABSTRACT

In a magnetic bearing apparatus provided at least with a touchdown bearing and a corrugated plate-like damper member inserted into an annular gap between the touchdown bearing and its retainer member, to keep on holding the corrugated plate-like damper member in a predetermined position without fail.

A cylindrical retainer member 9 is a thrust bearing retainer member and also a touchdown bearing retainer member. A touchdown bearing 4, i.e., a pair of roller bearings 4a and 4b disposed in upper and lower stages are received in an inner circumferential portion of the cylindrical retainer member 9. An annular gap G is formed between the inner circumferential surface of the cylindrical retainer member 9 and outer races of the pair of roller bearings 4a and 4b. A pair of corrugated strip steel plates 8a and 8b that are the corrugated plate-like damper members are inserted into this annular gap G. Also, a strip-like metal thin plate 10a is inserted while being clamped between the upper corrugated strip steel plate 8a and the lower corrugated strip steel plate 8b. Thus, the strip-like metal thin plate 10a functions as a positional offset preventing means of the pair of corrugated strip steel plates 8a and 8b.

FIG.1

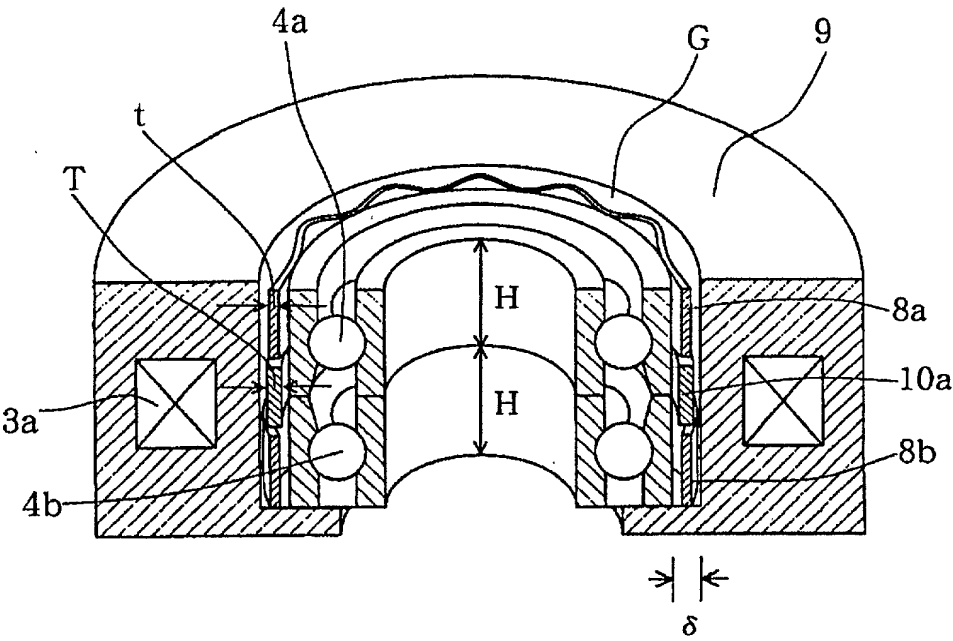


FIG.2

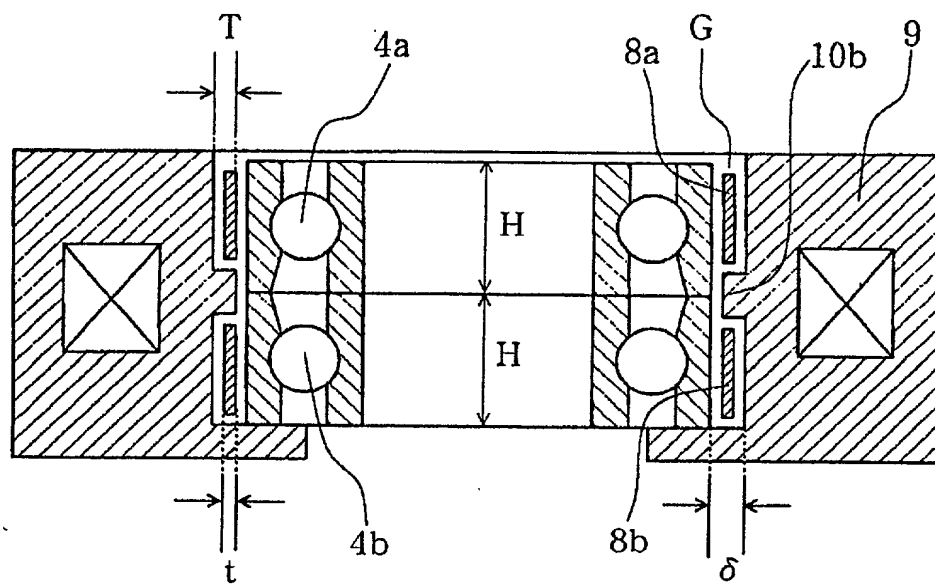


FIG.3

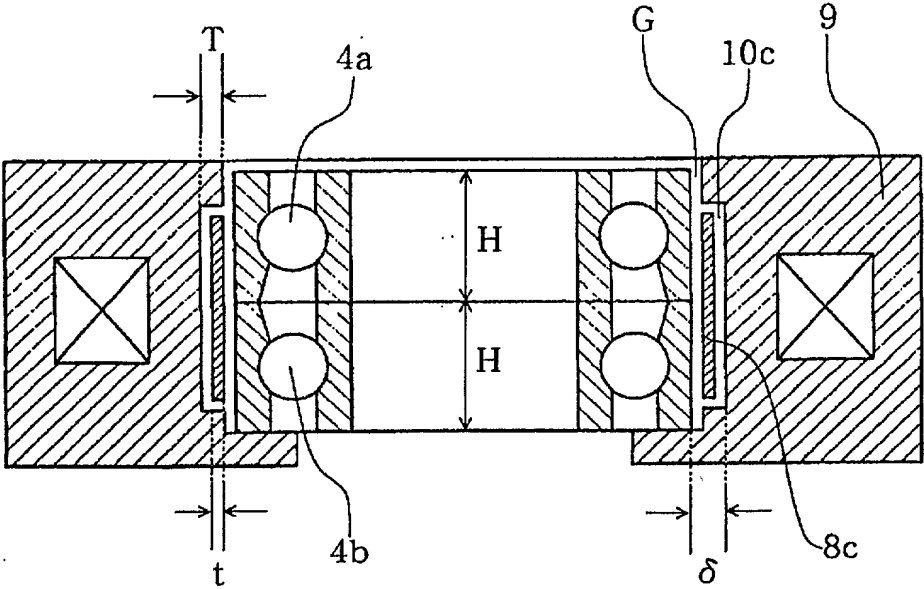


FIG.4

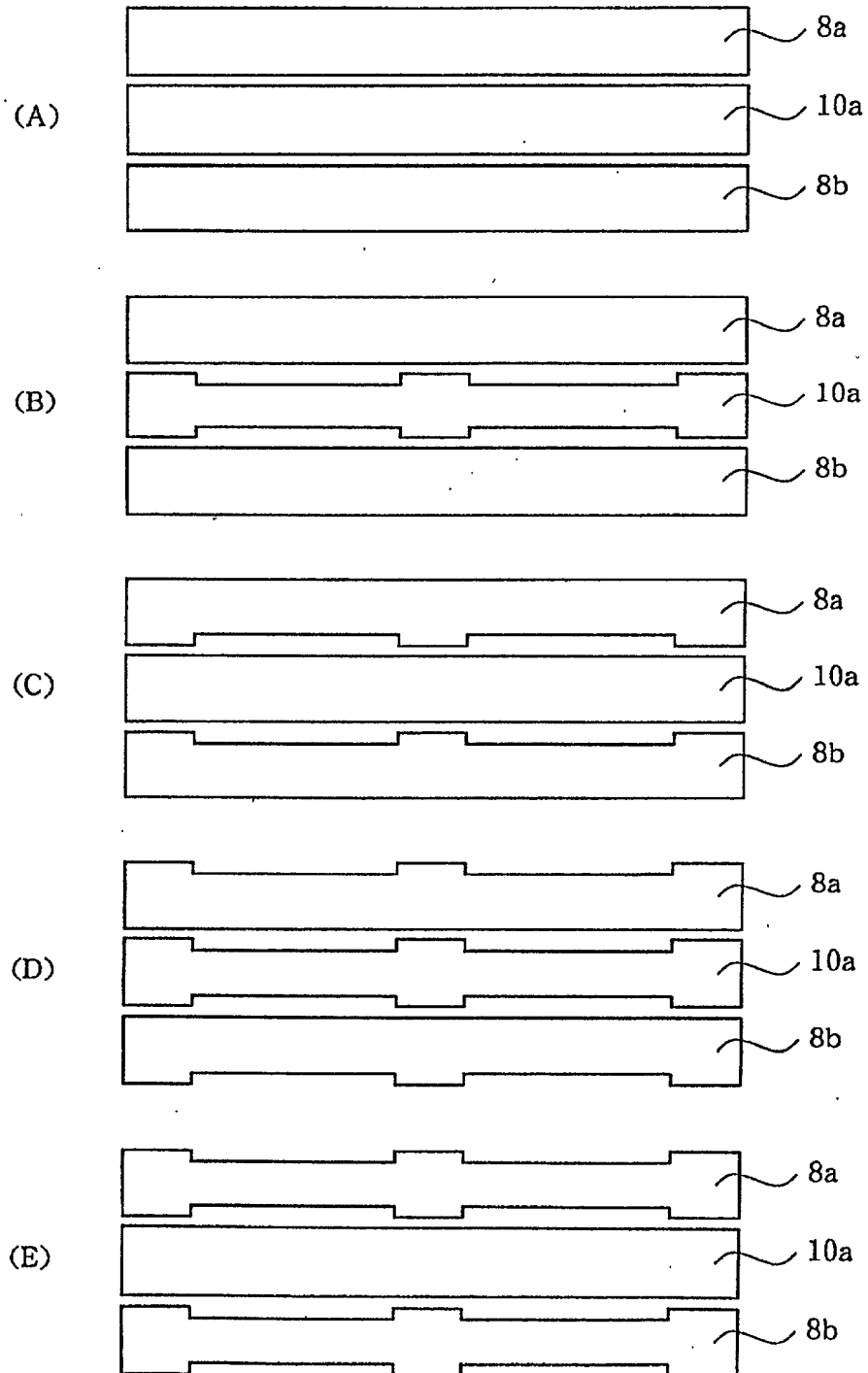


FIG.5

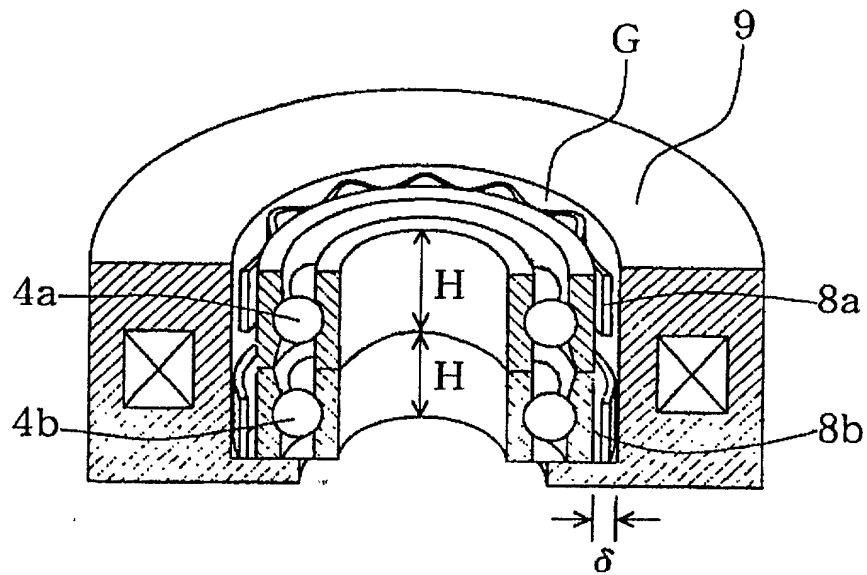


FIG.6

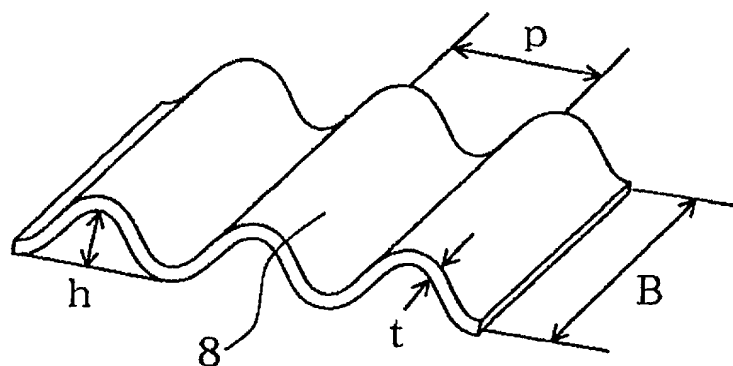
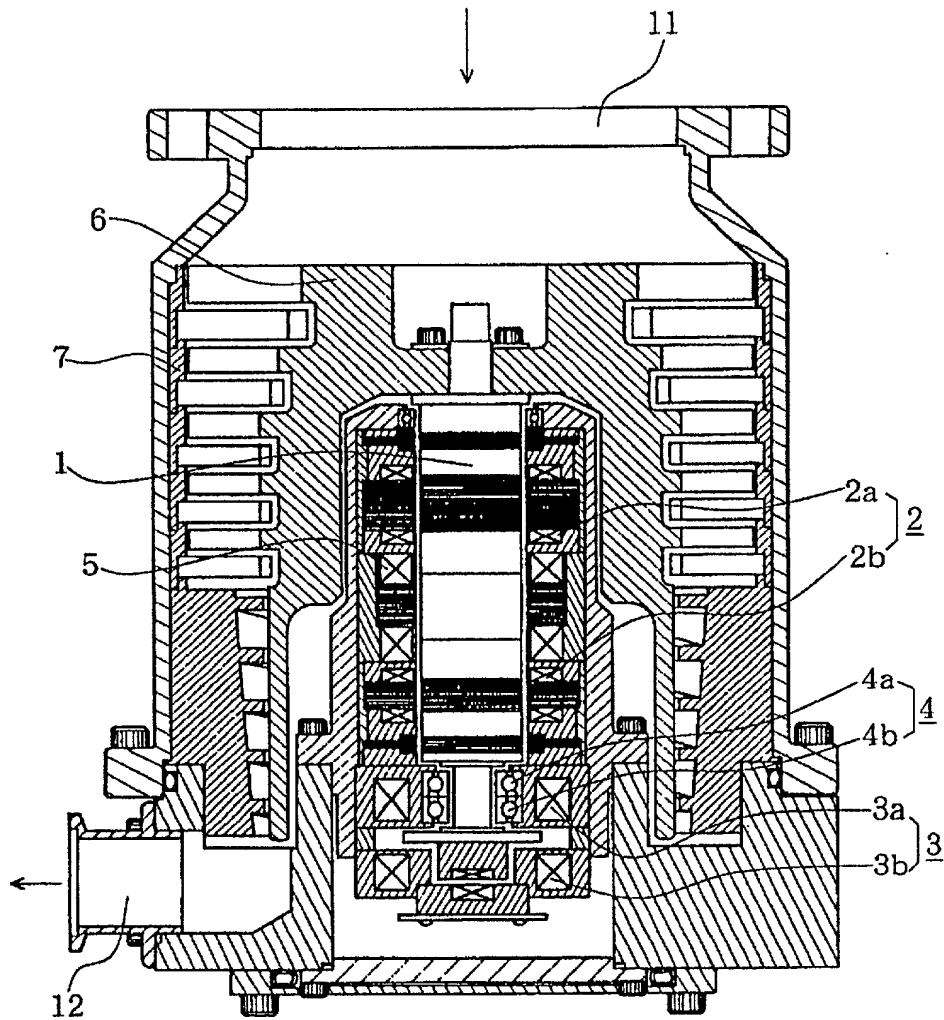


FIG.7



## DECLARATION FOR PATENT APPLICATION

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name; I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

MAGNETIC BEARING APPARATUS AND VACUUM PUMP as described and  
in PCT/JP00/02062 filed March 31, 2000

the specification of which (check one); ☐ is attached hereto; ☒ was filed on November 16, 2000  
as Application Serial No. 09/700,640 and was amended on (or amended

through) (if applicable). I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose information which is material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56(a). I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

## Prior Foreign Application(s)

(Number)	(Country)	(Day/Month/Year Filed)	Priority Claimed
11-093970	Japan	31/03/1999	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
000-087482	Japan	27/03/2000	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
			<input type="checkbox"/> Yes <input type="checkbox"/> No
			<input type="checkbox"/> Yes <input type="checkbox"/> No
			<input type="checkbox"/> Yes <input type="checkbox"/> No
			<input type="checkbox"/> Yes <input type="checkbox"/> No
			<input type="checkbox"/> Yes <input type="checkbox"/> No

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status - Patented, Pending or Abandoned)
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(Application Serial No.)	(Filing Date)	(Status - Patented, Pending or Abandoned)
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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

## POWER OF ATTORNEY

I (we) hereby appoint Bruce L. Adams, Registration No. 25,386, Van C. Wilks, Registration No. 25,027 and Franco S. De Liguori, Registration No. 36,497 whose post office address is: Adams & Wilks, 50 Broadway, 31st Floor, New York, New York 10004, as my (our) attorneys with full power of substitution and revocation, to prosecute this application, and to transact all business in the United States Patent and Trademark Office connected therewith.

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State or Country	State or Country
Date ✓	Signature ✓

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State or Country	State or Country
Date ✓	Signature ✓

☐ See third page for additional joint inventors.